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PATENT  
2786-203P



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Applicant: Zeev Smilansky Conf.: 5637  
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Filed: January 28, 2002 Examiner: UNKNOWN  
For: METHOD FOR COMPARING SIGNAL ARRAYS IN  
DIGITAL IMAGES

#4  
6-25-02

L E T T E R

Assistant Commissioner for Patents  
Washington, DC 20231

June 4, 2002

Sir:

Under the provisions of 35 U.S.C. § 119 and 37 C.F.R. § 1.55(a), the applicant(s) hereby claim(s) the right of priority based on the following application(s):

<u>Country</u>	<u>Application No.</u>	<u>Filed</u>
ISRAEL	141151	January 29, 2001

A certified copy of the above-noted application(s) is(are) attached hereto.

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Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By   
Charles Gorenstein, #29,271

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מספר: Number	141151
תאריך: Date	29-01-2001
הוקדם/נדחה: Ante/Post-dated	

בקשה לפטנט  
Application For Patent

אני, (שם המבקש, מענו ולגבי גוף מאוגדת מקום התאגדותו)  
I, (Name and address of applicant, and in case of body corporate-place of incorporation)

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בעל אמצאה מכח הדין שמה הוא  
Owner, by virtue of Right of Law of an invention the title of which is

שיטה להשוואת מערכי אותות בתמונות ספרתיות

(בעברית)  
(Hebrew)

Method for comparing signal arrays in digital images

(באנגלית)  
(English)

מבקש בזאת כי ינתן לי עליה פטנט

Hereby apply for a patent to be granted to me in respect thereof.

בקשת חלוקה Application of Division	בקשת פטנט מוסף Appl. for Patent of Addition	דרישת דין קדימה Priority Claim		
מבקשת פטנט from application	לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No. _____ מס' _____ Dated _____ מיום _____	No. _____ מס' _____ Dated _____ מיום _____			
P.O.A.: General כללי filed in case P128131		יפוי כח: הוגש בעניין		
המען למסירת מסמכים בישראל Address for Service in Israel				
REINHOLD COHN AND PARTNERS Patent Attorneys P.O.B. 4060, Tel-Aviv		C. 125624		
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For the Applicants, REINHOLD COHN AND PARTNERS By : — Ben Spurgin ✓		שנת 2001 Year January 28 of		
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שיטה להשוואת מערכי אותות בתמונות ספרתיות

Method for comparing signal arrays in digital images

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C. 125624

## METHOD FOR COMPARING SIGNAL ARRAYS IN DIGITAL IMAGES.

### FIELD OF THE INVENTION

The invention relates to methods of comparing the intensity of two signal arrays in digital images, for example digital images of a spot in a one- or two-dimensional electrophoresis pattern or a DNA chip.

### BACKGROUND OF THE INVENTION

A digital image may be considered to be an array of signals, where each pixel in the image produces a visible signal of a particular intensity. It is often of interest to compare two such signal arrays. For example, two protein mixtures can be separated by one of various separation techniques to produce two one- or two-dimensional separation patterns. A digital image of a spot in each pattern, corresponding to the same protein could be compared in order to compare the amount of the protein present in each mixture. As another example, a DNA chip having attached to it various oligonucleotide targets is incubated in the presence of probe oligonucleotides from two sources. The two probe species are differently labeled, so that each probe species produces a visible signal that is distinguishable from that of the other species. For example, one probe species may be labeled with a fluorescent dye that produces a red signal while the other probe species is labeled with a fluorescent dye that produces a green signal. A digital image of the red signal could then be compared with a digital image of the green signal in order to compare the amount of oligonucleotides binding to the chip in the two sources.

One well-known method for comparing the signal arrays in two digital images involves calculating the total intensity in each image and then calculating

vention, the two signal arrays to be compared are. The two arrays may be, for example, a single DNA chip that was simultaneously incubated with two different sources, where the probes from each source producing a distinct visible signal. For example, one array may be labeled with a fluorescent label producing a red signal and the other source labeled with a label producing a green signal. In the digital image, the red and green signal arrays in the digital image are separated, and are to be compared by the method of the

/s are superimposed upon one another, each pixel  $x_i$  is described by an ordered pair of numbers  $(I_1(x_i), I_2(x_i))$  where  $I_1(x_i)$  is the intensity of the signal of the pixel  $x_i$  in the first array, and  $I_2(x_i)$  is the intensity of the signal of the pixel  $x_i$  in the second array. A linear regression is performed on the points  $(I_1(x_i), I_2(x_i))$ . Within the context of the present invention, the term "linear regression" is used to include any method in which a straight line is fitted to a set of points, for example, a least squares fit of the points. The method described in the art. This also includes methods involving a filtering of the points where points are deleted from the set of points prior to determining the

- may be carried out in
- way of non-limiting
- which:

linear fit. In accordance with the invention, the two arrays are compared by means of the slope of the line produced by the linear regression analysis.

In another embodiment of the invention, two signal arrays are compared that are not superimposed upon one another. The two patterns may be, for example, digital images of spots in different one- or two- dimensional separation  
5 patterns such as produced by electrophoresis. The two arrays are first put into register with each other. Registration of the two patterns is described by means of a transformation  $T$  that maps a pixel  $x_i$  in the first pattern to a pixel  $T(x_i)$  in the second pattern. Methods for obtaining registration transformations are disclosed,  
10 for example, in Israel Patent Application 133562. Two arrays in register with each other under the transformation  $T$  are compared in accordance with the invention as follows. For each pixel  $x_i$  in the first array, an ordered pair of numbers  $(I(x_i), I(T(x_i)))$  is generated where  $I(x_i)$  is the intensity of the signal of a pixel  $x_i$  in the first array and  $I(T(x_i))$  is the intensity of the pixel  $T(x_i)$  in the second pattern that  
15 is in register with the pixel  $x_i$ . A linear regression analysis is applied to the points  $(I(x_i), I(T(x_i)))$ . In accordance with the invention, the two arrays are compared by means of the slope of the regression line produced by the linear regression analysis.

The invention may be used for the determination of differential gene  
20 expression. In this application, each of the signal arrays to be compared represents the level of expression of a particular gene. Typically, but not necessarily, the two arrays represent the level of the gene expression under different conditions. The invention may also be used for the determination of differential protein expression. In this application, each of the signal arrays to be  
25 compared represents the amount of a particular protein present in a sample.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting  
30 example only, with reference to the accompanying drawings, in which:

**Fig. 1** is a plot of the ordered pairs  $(I_1(x), I_2(x_i))$  where  $I_1(x_i)$  is the intensity of a signal produced by a first DNA probe species in the pixel  $x_i$ ,  $I_2(x_i)$  is the intensity of a signal produced by a second DNA probe species in the pixel  $x_i$ , the DNA probes being bound to DNA targets on a DNA chip;

5 **Fig. 2** shows two two-dimensional separation patterns;

**Fig. 3** shows an enlargement of first and second spots from the first and second separation patterns, respectively, of **Fig. 2**, and

**Fig. 4** shows a plot of the points  $(I(x_i), T(I(x_i)))$ , where  $I(x_i)$  is the intensity of a pixel  $x_i$  in the first spot of **Fig. 3** and  $I(T(x_i))$  is the intensity of a pixel  $T(x_i)$  in  
10 the second spot that is in register with the first spot under a transformation **T**.

## EXAMPLES

### Example 1 Two superimposed spots

A DNA chip having DNA targets bound on it was incubated in the presence of a sample containing first and second DNA probe species, where each probe  
15 species was labeled with a label producing a distinct visible signal. Each of the first and second probe species bound to a particular target on the chip thus produces a distinct signal array in a region of the chip where the target is located. For a pixel  $x_i$ , the intensity of the two signal arrays is represented by an ordered pair of  
20 numbers  $(I_1(x_i), I_2(x_i))$  where  $I_1(x_i)$  is the intensity of the signal produced by the first probe species in the pixel  $x_i$  and  $I_2(x_i)$  is the intensity of the signal produced by the second probe species in the pixel  $x_i$ . **Fig. 1** shows a plot of the ordered pairs  $(I_1(x_i), I_2(x_i))$ . A linear regression analysis was applied to the points  $(I_1(x_i), I_2(x_i))$  that produced the best linear fit **200** to the points. The slope of the line **200** was  
25 found to be 1.48, indicating that a probes of the second species binding to a particular target on the chip were present in the sample at an abundance of about 1.48 times that of probes of the first species binding to the same target. The two spots are compared by means of the slope of the line **200**.

### Example 2 Separated arrays

Two samples containing proteins are separated to produce a pair of  
30 two-dimensional separation patterns. **Fig. 2** shows a representation of two



two-dimensional separations patterns **305** and **310**. A spot **315** in the first pattern **305** is to be compared with a spot **320** in the second pattern **310**. Fig. 3 shows enlargements of the spots **315** and **320**, divided into pixels. The pixels in each spot form a signal array. Each pixel in the spot **315**, for example, the pixel **325** has an associated intensity  $I(x_i)$ . Similarly, each pixel  $y_i$  in the spot **320**, for example the spot **330**, has an associated intensity  $I(y_i)$ . A mapping **T** is found that maps each of a plurality of pixels in the spot **315** to a different pixel in the spot **320**. For example, the pixel **325** may be mapped into the pixel **330**.

If the two spots **315** and **320** consist of the same number of pixels, then the mapping **T** may be obtained by first putting the entire patterns **305** and **310** into register with each other. The patterns **305** and **310** are put in register with one another by means of a transformation **T** that maps each pixel  $x_i$  in the pattern **305**, for example the pixel **330** to a pixel  $T(x_i)$  in the pattern **310**. A transformation that puts the two patterns into register with each other may be found, for example, as disclosed in Israel Patent Application No. 133562. The restriction of the transformation **T** to the spot **315** maps pixels in the spot **315** to pixels in the spot **320**.

Another method that may be used to put the spots **315** and **320** into register with each other when the two spots consist of about the same number of pixels is to arrange the pixels in each spot in order of decreasing intensity. The mapping **T** is then defined that maps the  $n$ th pixel in the arrangement of the pixels of the spot **315** with the  $n$ th spot in the arrangement of the pixels of the spot **320**.

When the two spots **315** and **320** consist of about the same number of pixels, and the mapping **T** has been defined, pairs of numbers are  $(I(x_i), I(T(x_i)))$  formed where  $I(x_i)$  is in the intensity of a pixel  $x_i$  in the pattern **105** and  $I(T(x_i))$  is the intensity of the pixel  $T(x_i)$  in the pattern **115** that is in register with  $x_i$  under the transformation **T**. Fig. 4 shows a plot of the points  $(I(x_i), I(T(x_i)))$ . A linear regression analysis is applied to the points that produces the best linear fit **400** to the points. The slope of the linear fit **400** is found to be 4.8 indicating that the spot

320 contains about 4.8 as much protein as is present in the spot 315. The two spots are compared by means of the slope of the line 400.

If, say, the spot 315 consists of substantially more pixels than the spot 320, the following method may be used to put a plurality of the pixels of the spot 315 into register with pixels in the spot 320. The pixels in each spot are arranged in order of decreasing intensity. A predetermined fraction  $r_1$  of the pixels in the spot 315 are then deleted from the arrangement of the pixels of that spot, to produce a provisional arrangement of the pixels of that spot. A predetermined fraction  $r_2$  of the pixels in the spot 320 are then deleted from the arrangement of the pixels of that spot, to produce a provisional arrangement of the pixels of that spot.  $r_1$  and  $r_2$  are selected so that the two provisional arrangements consist of about the same number of pixels. Preferably, the pixels deleted to form the provisional arrangements are substantially uniformly distributed in each of the initial arrangements. Thus, about every  $1/r_1$ -th pixel is removed from the initial sequence of pixels from the spot 315 and about every  $1/r_2$ -th pixel is removed from the initial sequence of pixels from the spot 320. A transformation  $T'$  is then defined that maps the  $n$ th pixel in the provisional arrangement of the pixels of the spot 315 with the  $n$ th spot in the provisional arrangement of the spot 320.

Pairs of numbers are  $(I(x), I(T'(x_i)))$  formed where  $I(x_i)$  is in the intensity of a pixel  $x_i$  in the pattern 105 and  $I(T'(x_i))$  is the intensity of the pixel  $T'(x_i)$  in the pattern 115 that is in register with  $x$  under the transformation  $T'$ . Fig. 5 shows a plot of the points  $(I(x_i), T'(I(x_i)))$ . A linear regression analysis is applied to the points that produces the best linear fit 500 to the points. The slope of the linear fit 500 is multiplied by  $r_2/r_1$  to compensate for the deletion of points from the two spot arrangements.

It will also be understood that the system according to the invention may be a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a machine-readable memory tangibly

embodying a program of instructions executable by the machine for executing the method of the invention.

**CLAIMS:**

1. A method for comparing first and second signal arrays, the arrays being comprised of pixels, each pixel in an array having an intensity, the method comprising steps of:
  - 5 (a) associating to each of a plurality of pixels  $x_i$  in the first array a pixel  $T(x_i)$  in the second array, and
  - (b) applying a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.
2. The method according to Claim 1 wherein the first and second signal arrays  
10 are superimposed and  $T(x_i)=x_i$ .
3. The method according to Claim 2 wherein the first and second signal arrays are obtained by incubating a DNA chip in the presence of first and second probe species, the first probe species producing a signal that is distinguishable from a signal produced by the second probe species.
- 15 4. The method according to Claim 2 wherein the first and second signal arrays are obtained by staining a spot in separation pattern with first and second labels, the first label producing a signal that is distinguishable from a signal produced by the second label.
5. The method according to Claim 1 wherein the first and second arrays are not  
20 superimposed.
6. The method according to Claim 5 wherein the first and second signal arrays are spots in a first and second separation pattern, respectively.
7. The method according to Claim 6 wherein the first and second separation patterns are in register, and for each pixel  $x_i$  in the first spot,  $T(x_i)$  is the spot in the  
25 second separation pattern in register with  $x_i$ .
8. The method according to any one of the previous claims for use in determining differential gene expression or differential protein expression.
9. A method for determining differential gene expression of a gene comprising steps of:

- (a) obtaining digitized images of first and second signal arrays representing first and second expression levels of the gene, respectively, each pixel in an image having an intensity;
- (b) associating to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image, and
- (c) applying a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.

10. The method according to Claim 9 wherein the first and second signal arrays are superimposed and  $T(x_i)=x_i$ .

10 11. The method according to Claim 10 wherein the first and second signal arrays are obtained by incubating a DNA chip in the presence of first and second probe species, the first probe species producing a signal that is distinguishable from a signal produced by the second probe species.

12. The method according to Claim 10 wherein the first and second signal arrays are obtained by staining a spot in separation pattern with first and second labels, the first label producing a signal that is distinguishable from a signal produced by the second label.

13. A method for determining differential protein expression comprising steps of:

- (a) obtaining digitized images of first and second signal arrays representing first and second expression levels of the protein, respectively, each pixel in an image having an intensity;
- (b) associating to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image, and
- (c) applying a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.

14. The method according to Claim 13 wherein the first and second arrays are not superimposed.

15. The method according to Claim 14 wherein the first and second signal arrays are spots in a first and second separation pattern, respectively.

16. The method according to Claim 15 wherein the first and second separation patterns are in register, and for each pixel  $x_i$  in the first spot,  $T(x_i)$  is the spot in the second separation pattern in register with  $x_i$ .

17. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for  
5 comparing digitized images of first and second signal arrays, the images being comprised of pixels, each pixel in an image having an intensity, the method comprising steps of:

- (a) associating to each of a plurality of pixels  $x_i$  in the first image a pixel  
10  $T(x_i)$  in the second image, and
- (b) applying a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.

18. A computer program product comprising a computer useable medium having computer readable program code embodied therein for comparing digitized  
15 images of first and second signal arrays, the images being comprised of pixels, each pixel in an image having an intensity, the computer program product comprising:

computer readable program code for causing the computer to associate to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image, and

20 computer readable program code for causing the computer to apply a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.

19. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for  
25 determining differential gene expression of a gene comprising steps of:

- (a) obtaining digitized images of first and second signal arrays representing first and second expression levels of the gene, respectively, each pixel in an image having an intensity;
- (b) associating to each of a plurality of pixels  $x_i$  in the first image a pixel  
30  $T(x_i)$  in the second image, and

- (c) applying a linear regression analysis to the ordered pairs of numbers ( $x_i$ ,  $T(x_i)$ ) so as to produce a slope.

20. A computer program product comprising a computer useable medium having computer readable program code embodied therein for determining  
5 differential gene expression of a gene the computer program product comprising:

computer readable program code for causing the computer to obtain digitized images of first and second signal arrays representing first and second expression levels of the gene, respectively, each pixel in an image having an intensity;

10 computer readable program code for causing the computer to associate to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image, and

computer readable program code for causing the computer to apply a linear regression analysis to the ordered pairs of numbers ( $x_i$ ,  $T(x_i)$ ) so as to produce a  
15 slope.

21. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for determining differential protein expression comprising steps of:

(a) obtaining digitized images of first and second signal arrays representing  
20 first and second expression levels of the protein, respectively, each pixel in an image having an intensity;

(b) associating to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image, and

(c) applying a linear regression analysis to the ordered pairs of numbers ( $x_i$ ,  
25  $T(x_i)$ ) so as to produce a slope.

22. A computer program product comprising a computer useable medium having computer readable program code embodied therein for determining differential protein expression the computer program product comprising:

computer readable program code for causing the computer to obtain  
30 digitized images of first and second signal arrays representing first and second

expression levels of the protein, respectively, each pixel in an image having an intensity;

computer readable program code for causing the computer to associate to each of a plurality of pixels  $x_i$  in the first image a pixel  $T(x_i)$  in the second image,  
5 and

computer readable program code for causing the computer to apply a linear regression analysis to the ordered pairs of numbers  $(x_i, T(x_i))$  so as to produce a slope.

For the Applicants,  
**REINHOLD COHN AND PARTNERS**  
By:

*Ben Spungin*



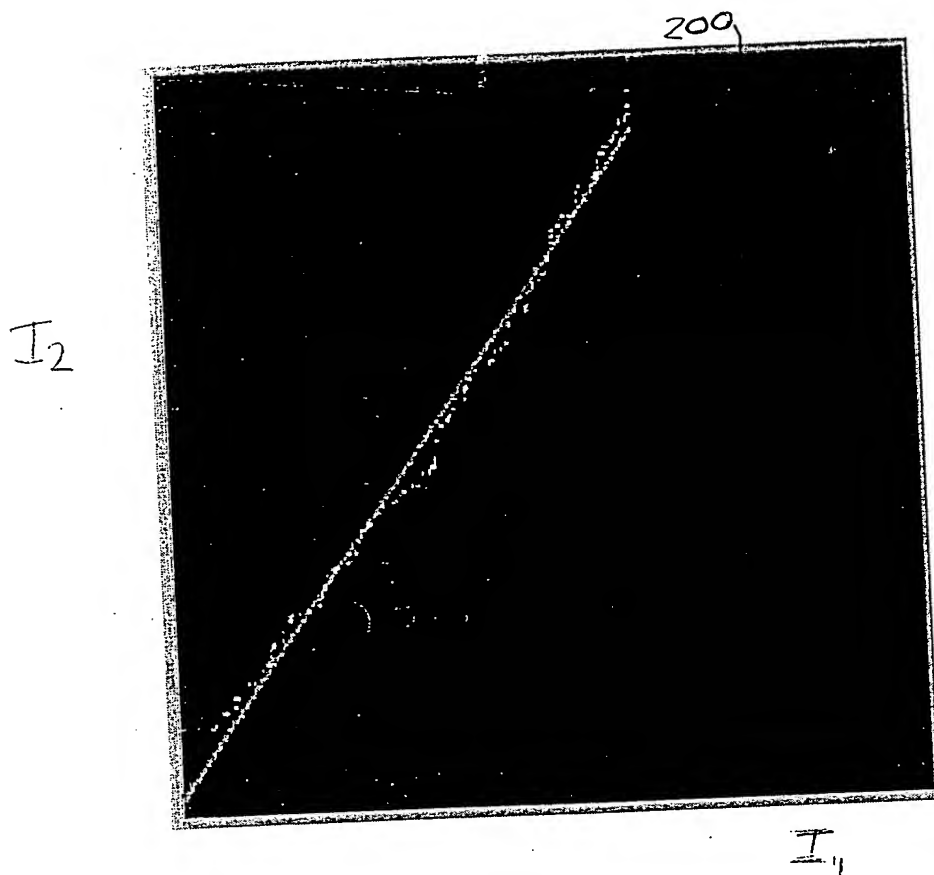


FIG. 1

305  
315

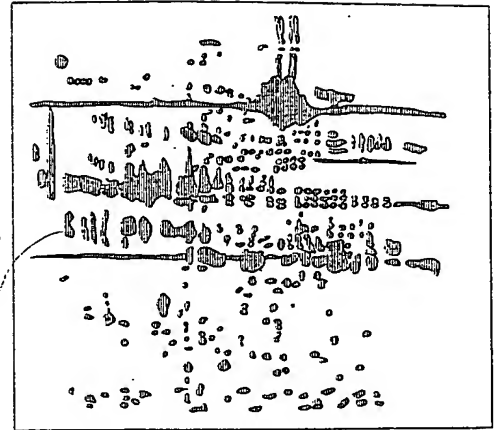


FIG. 1A

310  
320

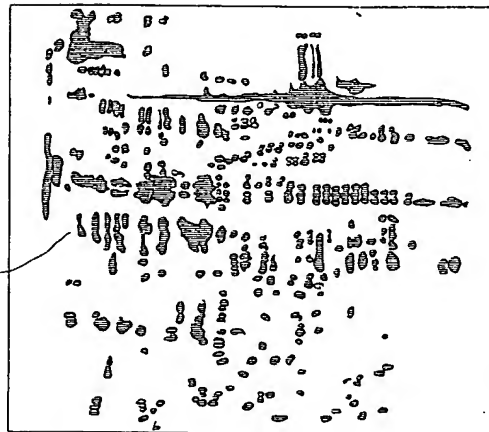


FIG. 1B

FIG. 2

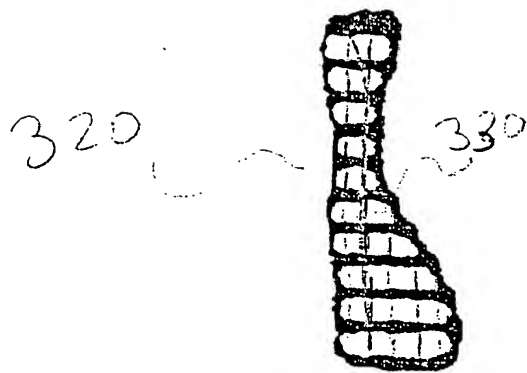
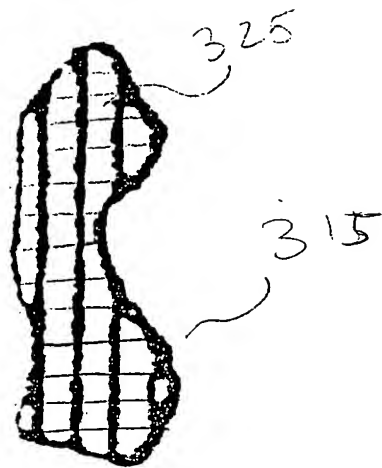
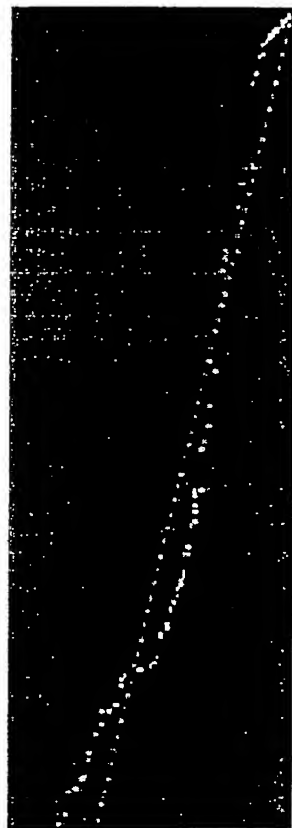


FIG. 3

2

I<sub>2</sub>



400

I<sub>1</sub>

FIG. 4

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